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POWER SYSTEM STABILIZER USING FUZZY LOGIC CONTROLLER

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ABSTRACT

Power system stabilizers are used to enhance the damping during low frequency oscillations. The paper presents a study of power system stabilizer using fuzzy logic to enhance stability of single machine infinite bus system. The power system stabilizer is developed by using the conventional and non-conventional controller. In the conventional controller a phase lead compensation technique is used and in non-conventional controller fuzzy set theory is used. The proposed power system stabilizer is designed for a single machine connected to an infinite bus power system. Speed deviation and acceleration of synchronous machine are taken as the input signals to the fuzzy controller and then the performance of conventional power system stabilizer (CPSS) and fuzzy logic based power system stabilizer (FLPSS) are compared. Result presented in the paper demonstrate that the fuzzy logic based power system stabilizer (FLPSS) design gives better performance than the conventional power system stabilizer.

Keywords: LFOs, SMIB, Power System Stabilizer (PSS), Fuzzy Logic Controller (FLC)

I. INTRODUCTION

Power systems are subjected to low frequency disturbances that might cause loss of synchronism and an eventual break down of entire system. The oscillations, which are typically in the frequency range of 0.2 to 3.0 Hz, might be excited by the disturbances in the system or in some cases might even build up spontaneously. These low frequency oscillations (LFOs) are generator rotor angle oscillations which limit the power transmission capability of a network and sometimes

even cause a loss of synchronism and an eventual break down of the entire system. For this purpose, power system stabilizers (PSSs) are used to generate supplementary control signals for the excitation systemin order to damp out these low frequency oscillations. The use of power system stabilizer has become very common in operation of large electric power systems. CPSS can be designed using classic control techniques such as root-locus, phase compensation, eigen value analysis etc. In this paper the CPSS use phase compensation technique where gain setting is design for specific operating condition, CPSS giving poor performance under different operating condition. The constant changing nature of power system makes the design of CPSS a difficult task. Therefore it is very difficult to design a stabilizer that could present good performance in all operation points of power system. To overcome the drawback of CPSS, fuzzy logic based technique has been suggested as solution. Using fuzzy logic based technique, mathematic model can be avoided, while giving good performance under different operation conditions. Fuzzy logic has the feature of simple concept, easy implementation and computationally efficient. The fuzzy logic based power system stabilizer model is evaluated on single machine infinite bus power system and then comparison studies performed between the conventional power system stabilizer (CPSS) and fuzzy logic based power system stabilizer (FLPSS). Result presented in the paper clearly demonstrates that the superiority of fuzzy logic based power system stabilizer (FLPSS) in comparison to the conventional power system stabilizer (CPSS).

2. SYNCHRONOUS MACHINE MODEL

The general system configuration of synchronous machine connected to infinite bus through transmission network is represented as the Thevenin's equivalent circuit where Et is terminal voltage, Eb is bus voltage. The general configuration of system and equivalent system shown in fig.1 and fig.2 respectively.

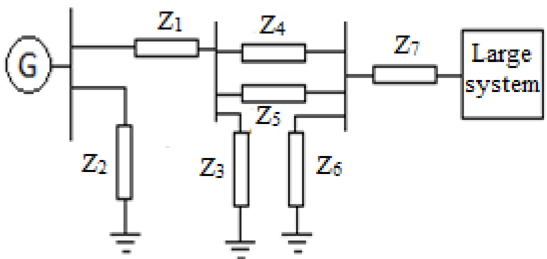

Fig.1 General Configurationof system

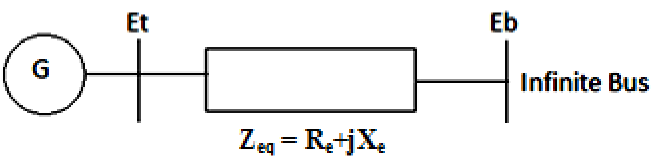

Fig.2 Equivalent system

The equations governing the synchronous machine model are:
Per unit stator voltage equation

$$e_d = p\,\Psi_d - \Psi_q\omega_r - R_a i_d \qquad (1)$$
$$e_q = p\,\Psi_q - \Psi_d\omega_r - R_a i_q \qquad (2)$$

Per unit rotor voltage equatin:

$$e_{fd} = p\,\Psi_{fd} - R_{fd} i_{fd} \qquad (3)$$
$$0 = p\,\Psi_{1d} + R_{1d} i_{1d} \qquad (4)$$
$$0 = p\,\Psi_{1q} + R_{1q} i_{1q}$$

Per unit stator flux linkage equation:

$$\Psi_d = -\,(L_{ad} + L_l) i_d + L_{ad} i_{fd} + L_{ad} i_{1d} \qquad (5)$$
$$\Psi_q = -\left(L_{aq} + L_l\right) i_q + L_{aq} i_{1q} + L_{aq} i_{2q} \qquad (6)$$

Per unit rotor flux linkage equation:

$$\Psi_{fd} = L_{ffd} i_{fd} + L_{f1d} i_{1d} - L_{ad} i_d \qquad (7)$$
$$\Psi_{1q} = L_{11q} i_{1q} + L_{aq} i_{2q} - L_{aq} i_q \qquad (8)$$

Per air gap-torque equation:

$$T_e = \Psi_d i_q - \Psi_q i_d \qquad (9)$$

Motion equations:

$$\frac{d\delta}{d_t} = \omega - \omega_b \qquad (10)$$
$$\frac{d\omega}{d_t} = \frac{\omega_b}{2H}(T_m - T_e) \qquad (11)$$

3. POWER SYSTEM STABILIZER

The basic function of power system stabilizer is to add damping to electro mechanical oscillations for generator excitation system in order to damp low frequency oscillations. CPSS essentially use the power amplification capability of generator to generate a damping torque in phase with the speed change of the generator rotor. This is achieved by injecting a stabilizing signal into the excitation system voltage reference in such a way that a component of electrical torque proportional to the rotor speed is produce.

The CPSS can use various inputs, such as the speed deviation of the generator shaft, the change in electrical power or accelerating power or even the terminal bus frequency. In this paper speed deviation $\Delta\omega_r$ is used as input in CPSS and output of any CPSS is voltage signal.
The block diagram of CPSS is shown in fig.3. It consists of a gain block, signal wash out block, phase compensation block. Each block performs a specific function.

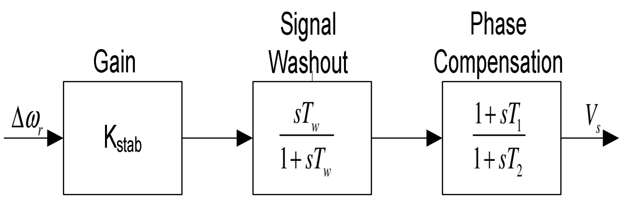

Fig.3: Block diagram of CPSS

1). Gain block

The stabilizer gain K_{stab} determines the amount of damping introduced by the CPSS. Ideally the gain should be set at a value corresponding to maximum damping.

2). Signal washout block

The signal washout block serves as high pass filter, with time constant Tw high enough to allow signals associated with oscillations in $w_r$to pass unchanged, which removes d.c signals. Without it, steady changes in speed would modify the terminal voltage. It allows PSS to respond only to changes in speed. The value of Tw is not critical and may be in the range of 1 to 20 seconds. The main consideration is that it should be long enough to pass stabilizing signals at the frequencies of interest unchanged, but not so long that it leads to undesirable generator voltage excursions during system islanding conditions.

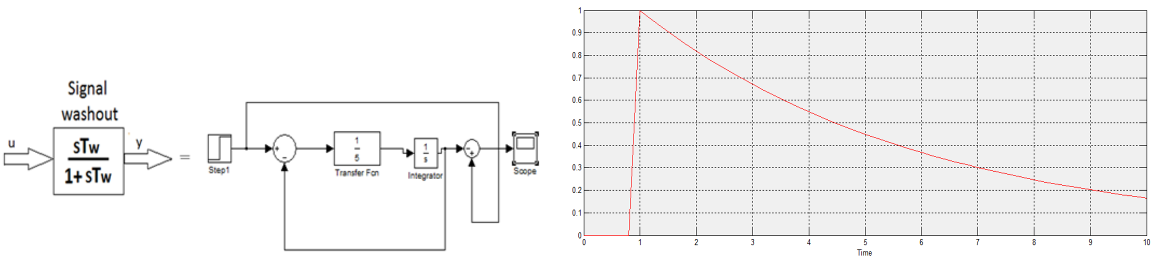

Fig.4 Design of washout block

The transfer function as shown in fig4 should be a high pass filter. Transfer functions gain should be zero when the frequency of oscillations to be zero. TheCPSS should give zero output under steady state condition. So adding this block in cascade with the other block of a CPSSensures that the output is zero in steady state. If there is a step change in u, the output of this block will be as shown in fig 4.

3). Phase Compensation Block

The phase compensation block provides the appropriate phase lead characteristic to compensate for the phase lag between exciter input and generator electrical torque.The phase compensation having a single first order block as shown in fig.5. Or having more first order blocks or second order blocks with complex roots. Basic function of this phase compensator is to provide phase lead so normally it known as phase lead controller or phase lead compensator.

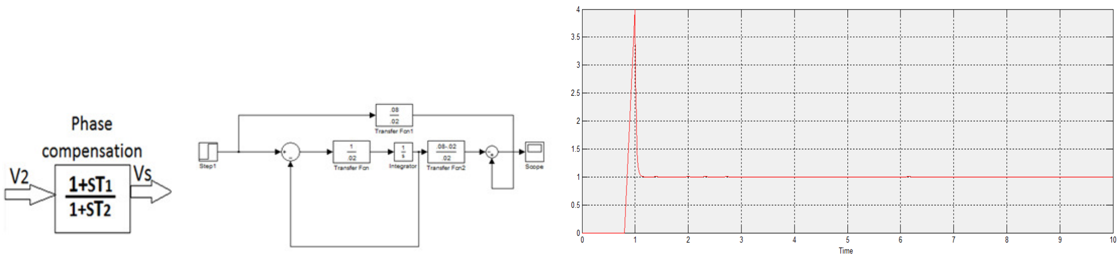

Fig.5: Design of phase compensator

If we choose T1 greater than T2 we get a lead compensator and got a maximum phase lead which is known as centre frequency fc.

$$fc= \frac{1}{2\pi}\frac{1}{\sqrt{T1*T2}} \tag{12}$$

by tuning T1 and T2 we can change the centre frequency.

4. FUZZY LOGIC CONTROLLER:

Since the concept of fuzzy logic given by zadeh in 1965, it has found application in various areas including a controller for PSS. A fuzzy controller as shown in fig.6 comprises of four stages: fuzzification, a knowledge base, decision making, and defuzzification. The fuzzification interface coverts input data into suitable linguistic values that can be viewed as label fuzzy sets. The knowledge base comprises knowledge of application domain and attendant control goals by means of set of linguistic control rules. The decision making is the aggregation of output of various control rules that simulate the capability of human decision making. The defuzzification interface performs scale mapping, which converts the range of values of output variables into corresponding universe of discourse.

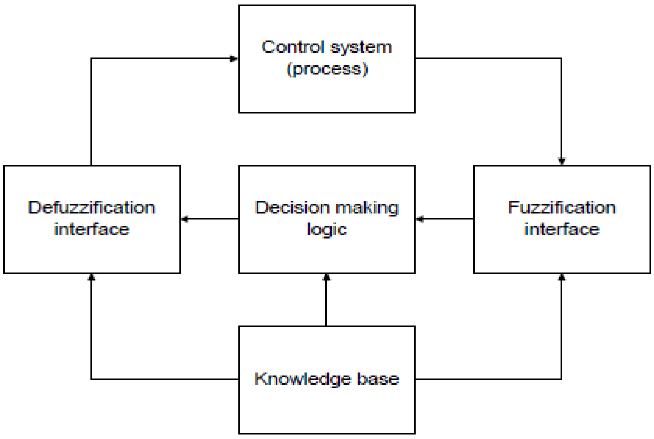

Fig.6: The principle design of FLC

The fuzzy controller design consists of the following steps:
1. Identification of input and output variables.
2. Construction of control rules.
3. Establishing the approach for describing system in terms of fuzzy sets, i.e. establishing fuzzification method and fuzzy membership functions.
4. Selection of the composition rule of inference.
5. Defuzzification method, i.e. transformation of the fuzzy control statement into specific control actions.

5. DESIGN OF FUZZY LOGIC BASED PSS

The fuzzy controller used in PSS is normally a two input and a single output component. It is usually a MISO system. The design of fuzzy logic based PSS shown in fig. The two inputs are change in angular speed (speed deviation) and rate of change of angular speed (acceleration speed) whereas output of fuzzy logic controller is a voltage signal (Vpss).

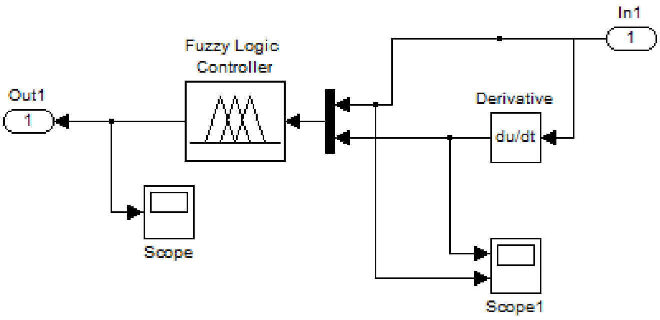

Fig.7: Design of fuzzy logic based PSS

6. INPUT/OUTPUT VARIABLES

The design starts with assigning the mapped variable inputs/output of the fuzzy logic controller (FLC). The first input variable to the FLC is the generator speed deviation and the second is acceleration. The output variable to the FLC is the voltage. After choosing proper variables as input and output of fuzzy controller, it is required to decide on the linguistic variables. These variables transform the numeric values of the input of fuzzy controller to fuzzy quantities. The number of linguistic variables describing the fuzzy subsets of a variable varies according to the application. Here seven linguistic variables for each of the input and output variables are used to describe them. The membership functions (MF) maps the crisp values into fuzzy variables. The triangular membership functions are used to define the degree of membership. Here for each input variable, seven labels are defined namely, NB, NM, NS, ZE, PS, PM and PB. Each subset is associated with triangular membership function to form a set of seven membership functions for each variable.

Table.1: Membership functions for fuzzy variables

NB	NEGATIVE BIG
NM	NEGATIVE MEDIUM
NS	NEGATIVE SMALL
ZE	ZERO
PS	POSITIVE SMALL
PM	POSITIVEMEDIUM
PB	POSITIVE BIG

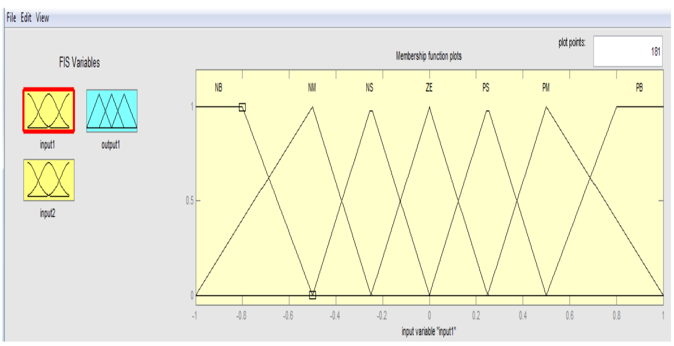

Fig.8: Membership function for speed deviation

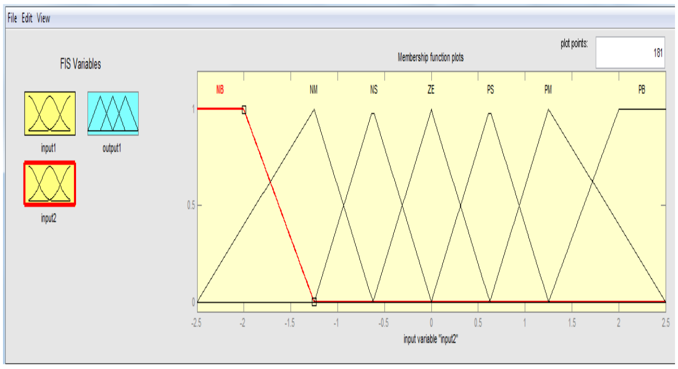

Fig.9: Membership function for acceleration

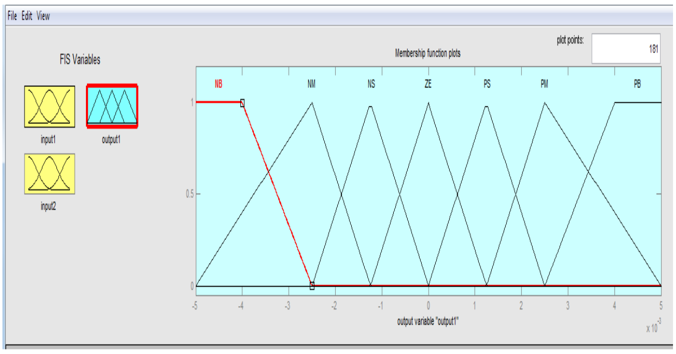

Fig.10: Membership function for voltage Vpss

The membership function for speed deviation, acceleration and voltage are shown in fig 8,9,10 respectively. Knowledge base involves defining the rules represented as IF-THEN rules statements governing the relationships between input and output variables in terms of membership functions. In this stage the input variables speed deviation and acceleration are processed by the inference engine that execute 7 × 7 rules represented in rule Table.2Each rule conjuncts speed deviation($\Delta\omega$) and acceleration fuzzy set values. The knowledge required to generate the fuzzy rules can be derived from offline simulation. Some knowledge can be based on the understanding of the behaviour of the dynamic system under control. For monotonic systems, a symmetrical rule table is very appropriate, although sometimes it may need slight adjustment based on the behaviour of the specific system.If the system dynamics are not known are highly nonlinear, trial and error procedures and experience play an important role in defining the rules.

Table.2: Decision table of 49 rules

Speed Deviation	Acceleration						
	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NS	ZE	ZE	PM	PB	PB
PS	NM	NS	PS	PM	PM	PB	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	ZE	PM	PB	PB	PB	PB

Decision table.2 shows the result of 49 rules, where a positive control signal is for the deceleration control and a negative signal is for acceleration control. In the rules of a proposed FLPSS, the input variables are connected by an 'AND' method.

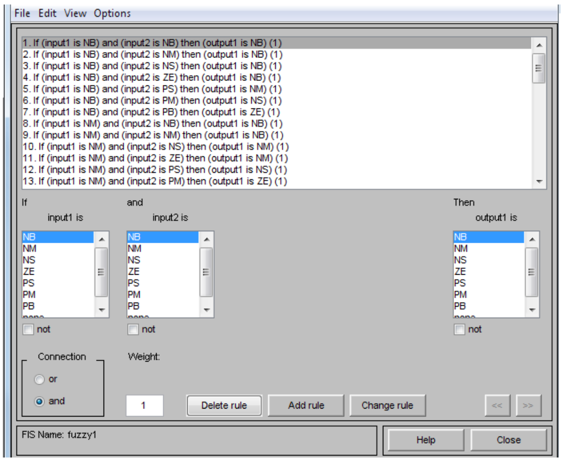

Fig.11: Fuzzy input and output rule editor

The example of first rule is: "if speed deviation is NB (negative big) AND acceleration is NB (negative big) THEN PSS output of fuzzy U is NB (negative big)". The example of second rule is:"if speed deviation is NB (negative big) AND acceleration is NM (negative big) THEN PSS output of fuzzy U is NB (negative big)" as shown in fig.11.

7. SIMULATION RESULTS

7.1. Single Machine Infinite Bus

The synchronous machine is connected to infinite bus system (SMIB). The synchronous machine parameters initial values are calculated in MATLAB M- file. The synchronous machine is develop by state space representation. The synchronous machine operated in different operating condition without PSS as shown in fig.12. The synchronous machine subjected to disturbance provide by changing mechanical torque (Tm).

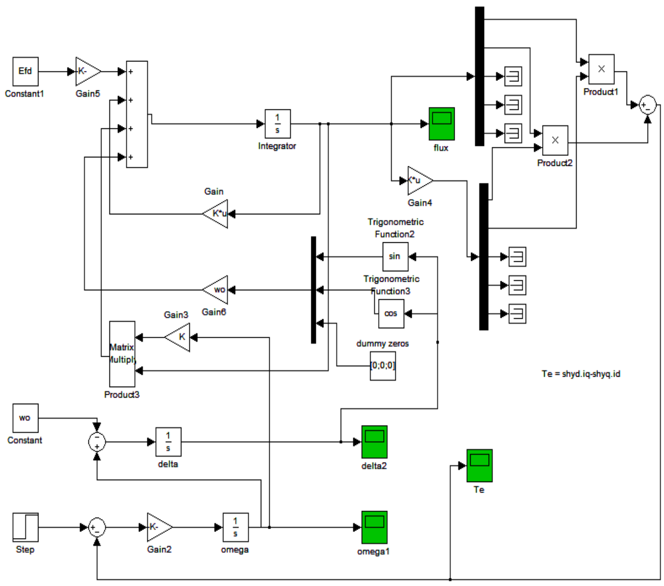

Fig.12: Synchronous machine connected with infinite bus without CPSS

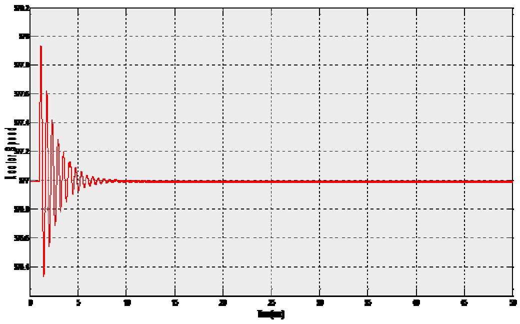

Fig.13: Rotor speed at mechanical torque (Tm+0.2pu) increase without CPSS

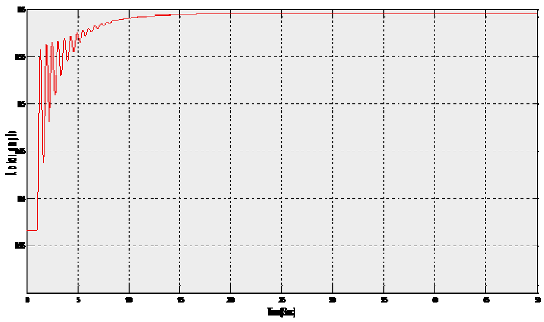

Fig.14: Rotor angle at mechanical torque (Tm+0.2pu) increase without CPSS

Fig.13 and 14 are shown the rotor speed oscillations and rotor angle oscillations respectively. In fig.13 shown that, rotor speed oscillations are damped out nearly 10 sec.

7.2 SMIB system under unbalanced condition with CPSS

The SMIB system is connected to CPSS under unbalance condition as shown in fig.15The CPSS input is the speed deviation (change in speed with reference to base speed) and output is the Vpss. CPSS is damped the oscillations of rotor speed and rotor angle.

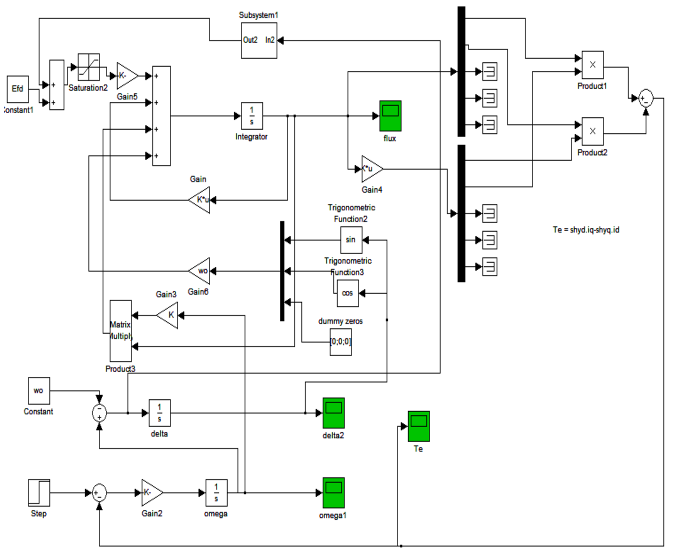

Fig.15: SMIB system under unbalanced condition with CPSS

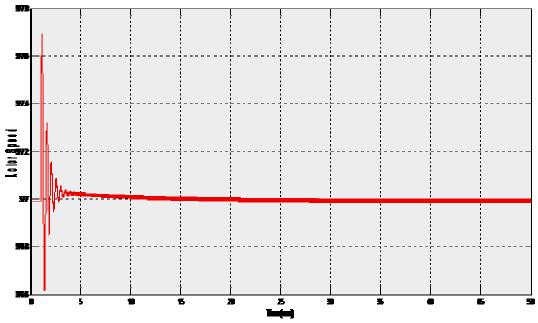

Fig.16: Rotor speed at mechanical torque (Tm+0.2pu) increase with CPSS

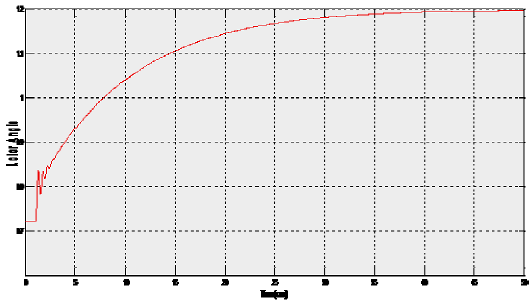

Fig.17: Rotor angle at mechanical torque (Tm+0.2pu) increase with CPSS

As shown in fig.16 rotor speed oscillation damped at nearly 5 second and rotor oscillations are also decreased.

7.3 SMIB system under Unbalanced Condition with FLPSS

Fuzzy logic controller is used as the power system stabilizer. The fuzzy logic controller has two inputs; one is speed deviation and second is acceleration fig.18 shows the fuzzy logic PSS connected with SMIB system.

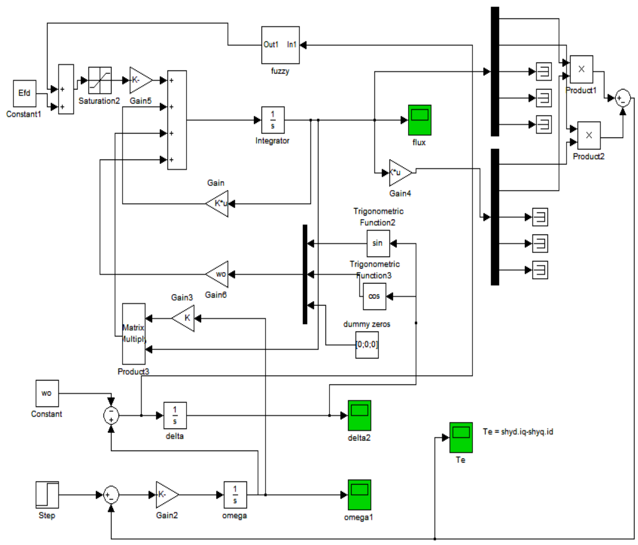

Fig.18 SMIB system under unbalanced condition with FLPSS

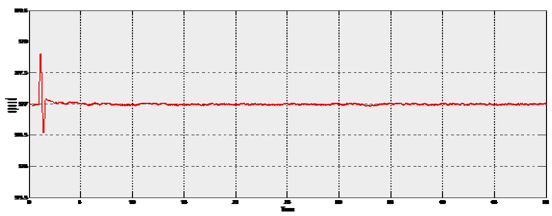

Fig.19. Rotor speed at mechanical torque (Tm+0.2pu) increase with FLPSS

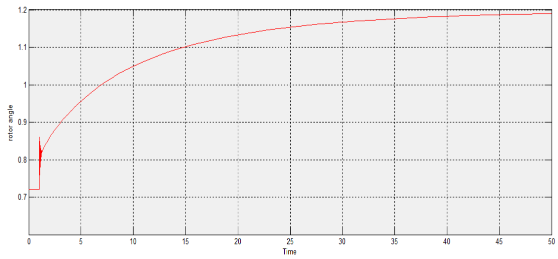

Fig.20. Rotor angle at mechanical torque (Tm+0.2 pu) increase with FLPSS

After using the fuzzy logic PSS show that, the rotor speed is steady state at 2.5 second. The oscillations of rotor speed are damp in just 2.5 second so we can say that FLPSS areprovided good damping. From above results can be summarized as below.

Table.3: comparison of without CPSS with CPSS and with FLPSS

SETTLING TIME (sec)		
Without CPSS	With CPSS	With FLPSS
10	5	2.5

CONCUSION

In this paper the fuzzy logic based power system stabilizer is introduced. Simulation results shows that the fuzzy logic power system stabilizer (FLPSS) has increased the damping of the system causing it to settle back to steady state in much less time than the conventional power system stabilizer (CPSS) and it also decrease the peak value. Therefore, it can be conclude that the performance of fuzzy logic power system stabilizer (FLPSS) is better than conventional power system stabilizer (CPSS).

APPENDIX A

a) SynchronousMachine Rating:
555 MVA, 24 kV, 60 Hz, 2 poles

b) Synchronous Machine Parameter:
Pt =0.5, Qt=0,Et =1.0, H=4, $F0$=60 Hz, Lad=1.66,
Laq=1.61, $L1q$=0.7252, Ra=0.003, $L1d$=0.1713

c) PSS Parameter:
$T1$=0.08, $T2$=0.02, Tw=5 sec, $KSTAB$ =0.001

APPENDIX B

List of Abbreviations

ω_r	Angular velocity of rotor, rad/sec
ω_0	Rated velocity of rotor, rad/sec
H	Inertia constant,
Tm	Mechanical torque
Te	Electromagnetic torque
Pt	Active power
Qt	Reactive power
ϕ	Power factor angle
δi	Internal rotor angle
Et	Armature terminal voltage
ed	d-axis stator voltage
eq	q-axis stator voltage
efd	Field voltage
ψd	d-axis stator flux linkage
ψq	q-axis stator flux linkage
Ψfd	d-axis rotor flux linkage
$\psi 1d$	q-axis damper winding flux linkage
id	d-axis terminal current
iq	q-axis terminal current
ifd	Field current
$i1q$	q- axis damper winding current
Ra	Armature resistor
Rfd	field winding resistance
$R1q$	q-axis damper winding resistance
Lad	d-axis mutual inductance
Laq	q-axis mutual inductance

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